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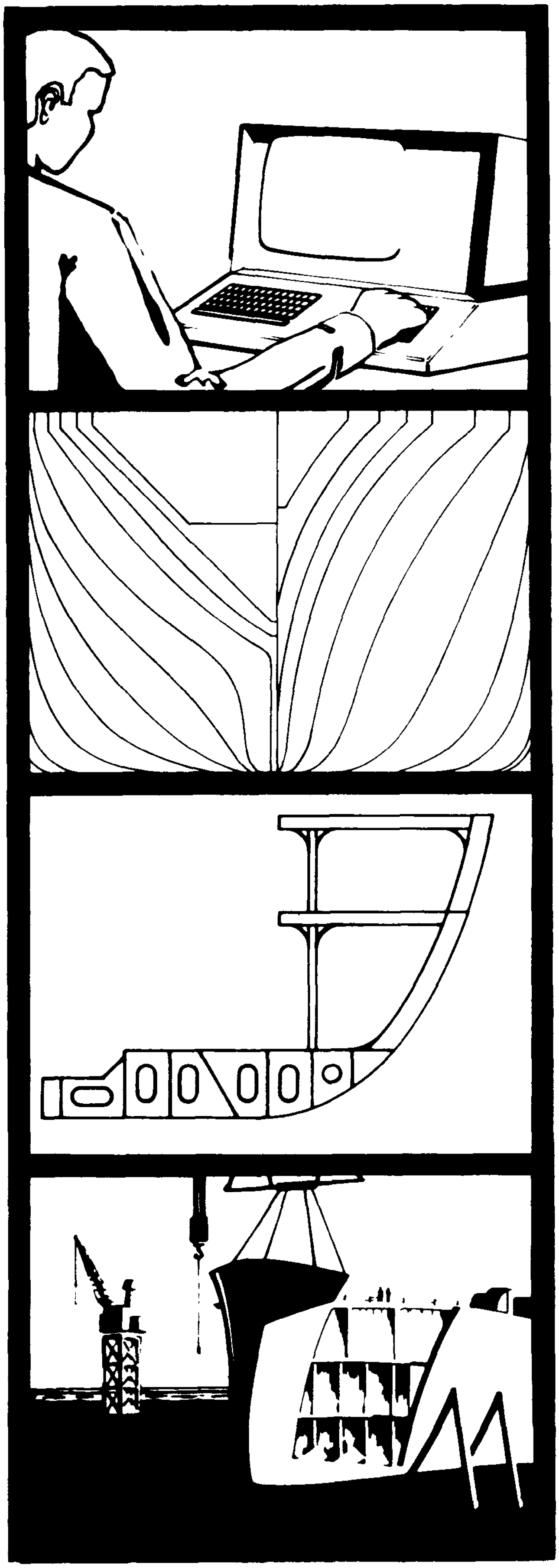

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NEW APPLICATIONS OF INDUSTRIAL ROBOTS TO SHIPBUILDING*

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ABSTRACT

Based on shipyard visits and a review of current ship construction, several new applications of industrial robots to shipbuilding are proposed. Preliminary estimates indicate that the time required to perform certain shipyard tasks could be decreased by 50% to 80% by the addition of various robot workstation concepts. Though control of robot workstations may eventually be integrated into CAD/CAM systems, manual techniques can currently be adopted, permitting a worker to program a robot station. Applications include, but are not limited to:

(1) Use of robots for welding in both fixed shop installations and movable field installations.

(2) Use of robots for flame or plasma arc cutting of irregularly shaped pieces such as profiles.

(3) Use of robots for grinding.

(4) Use of robots for blasting and painting operations, particularly in the shop environment where booths surrounding the equipment can be used to shield other workers and to keep the shop clean.

Although industry is now developing systems for many of these applications, particularly welding, painting, and grinding, additional controls and sensors will be needed to facilitate their implementation in the shipyard. Controls are required to program a robot more quickly to carry out a particular task. Sensors are required to slightly modify the robot's course as workpieces change shape as in welding, for example.

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BACKGROUND

Shipbuilding is highly labor-intensive--even more so in the United States than in Japan or Europe. To advance automation in our nation's shipbuilding industry is essential for reasons of economy, health, and national security. Specifically, we need to reduce the rising cost of shipbuilding and improve its quality, decrease the number of undesirable tasks in accordance with OSHA and EPA regulations, and prepare for contingencies in which labor skills could become scarce.

Advanced automation is particularly needed for arc welding, but is also important for other shipbuilding tasks. Since these tasks frequently involve individually made parts, they can be fabricated only through the use of highly programmable automation, which is characterized by flexibility, adaptability, and ease of training. An industrial robot--consisting of an arm, tool package, sensors, and a computer-based control mechanism for training and execution--is a programmable system.

Within the last **15** years industrial robots have been introduced into several sectors of industry to replace human workers performing undesirable tasks--tasks that are harmful, hazardous, strenuous, unpleasant, and dull. The use of industrial robots has yielded 'an increase in both productivity and product quality.

Nevertheless, despite their proven capabilities and benefits, industrial robots are not yet working for the shipbuilding industry. This is primarily because robots are neither mobile nor adaptable to variations in workpieces and the environment; e.g., they must contend with poor fitup in arc welding and variability of assemblies. Another impediment is the substantial engineering research and development work that is required to develop and debug the first robot workstations; capital investment is estimated to be from $35,000 to $150,000 per robot workstation.

Advantages of robot workstations in shipbuilding would be:

(1) Robots can have significantly higher throughput than manual workers because both the duty cycle and power of the tools can be substantially increased.

(2) Improvement in working conditions: machine operators and supervisors will be required.

(3) Increased productivity will alter traditional work methods and attract work to the more productive robot workstations. For example, in addition to doing the customary blasting jobs, a robot blasting center might be used to reduce the manual labor in cleaning welded joints, a task traditionally done by chipping, sanding, and wire brushing.

(4) Dirty jobs such as painting and blasting that would normally not be performed indoors, can be enclosed in dust- or fume-proof booths vented to the outside.

(5) Robot workstations can be introduced to alleviate production bottlenecks or to increase productivity as capital equipment funds are available and return on investment is sufficient.

(6) Robot systems are amenable to CAD/CAM implementation. Cutting, grinding, blasting, welding, and painting programs can be generated interactively by computer and automatically sent to robot workstations.

Technical constraints can be reduced by adding the feature of adaptability to industrial robots by means of sensors and computer control. Development of specially engineered tool packages such as welding head, plasma arc cutting head, or grinding head will permit robots to boost production productivity in many areas. Techniques for faster manual and NC programming will boost production even further. How the technical capabilities can be organized is shown in Figure 1. The realization of these capabilities has been the subject of research and development in programmable automation by the Industrial Automation Group of SRI International [4] and by other institutions **[5].**

Current technical constraints can be further reduced by using semiautonomous teleoperation, a technique whereby a combination of manually and computer-controlled robots is applied. Manual control can be used now before new systems are deployed and available.

Development constraints could be eased if the government would participate. Government agencies such as the Department of the Navy or Department of Commerce (Maritime Administration) might speed the application of robot technology to industry by carefully selecting,

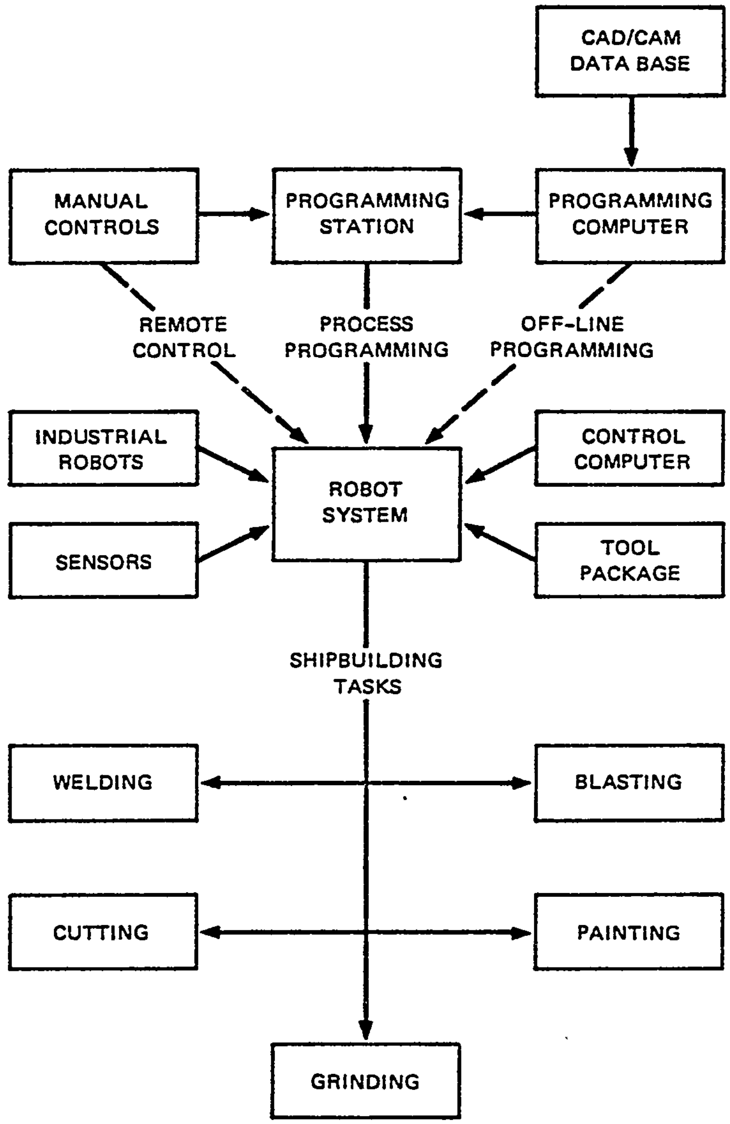


FIGURE 1 ORGANIZATION OF A ROBOT SYSTEM IN SHIPBUILDING

supporting, and monitoring research and development projects. Cooperation among users, 'suppliers, and research and development laboratories would also expedite results in this area.

Supported by the Naval Material Command under technical direction of the Naval Sea Systems Command, the Industrial Automation Group at SRI carried out a feasibility study [1] to examine how shipbuilding tasks are currently performed, to determine which labor-intensive or undesirable tasks can be performed automatically or semiautomaticaly (employing on-line manual control) by robot systems, and to conceptually design such systems.

NARROWING THE FIELD OF SHIPBUILDING TASKS

We studied possibilities of applying robot automation to shipbuilding tasks in several ways. Our approach included a survey of pertinent shipbuilding publications, 12 man-days in visits to several shipyards, and personal communications by phone and letter to shipyard personnel. , We surveyed existing industrial robots and associated equipment, either commercially available or in development stages, that might be used in combination to perform automated shipbuilding tasks.

Two previous studies are-pertinent to this discussion:

(1) A Navy report, entitled "High-Cost Factors of Ship Construction," describes shipyard tasks with associated numbers of man-hours for each task by type of ship. In this report labor-intensive work groups are clearly defined and ranked.

(2) **A** maritime administration report, entitled "Feasibility Study of Semiautomatic Pipe Handling System and Fabrication System," **[3]** present an in-depth application of automation to one of these work groups.

Based on our visits to four shipyards, we identified three work groups amenable to robots:

* Arc welding and cutting
* Spray painting and blasting
* Chipping and grinding.

These three work groups are listed in the order of decreasing percent of man-hours each in Table ,l. Note that welding, the largest group, is broken down into three parts for more detailed analysis.

Table 1

EVALUATION OF WORK GROUPS

Work Group	Man* Hours (percent)	Labor Intensive	Work Environment	Robot Technical Solution	Relative Robot Automation costs
Welding	12.8		undesirable		
Structural	8.3	yes		feasible	moderate
Pipe	3.2	moderate		feasible	moderate
Burning	1.3	no		limited	low
Painting & Blasting	4.5	yes	harmful if unprotected	feasible but limited	low
Chipping & Grinding	2.0	yes	very undesirable	feasible but limited	low

*Based on overall shipyard operation [2].

Our decision to consider conceptual designs for these areas is based primarily on the feasibility of a robot technical solution. Where we judge a solution feasible (even if limited) or low cost, conceptual designs are developed. Automating pipe welding is given only minor treatment here because of its extensive coverage in the Avondale Report [2].

NEW ROBOT SYSTEMS FOR SHIPBUILDING

Using robots in shipbuilding offers two principal advantages. The first one is increased operator factors--the operator duty cycle in performing a given task. A human worker welding, burning, grinding, or blasting spends only 23 to 30 percent of his time in productive work. A robot system, on the other hand, can perform these jobs continuously.

The second advantage of using robots is the increased tool power. A robot can carry heavier, more powerful, and more dangerous tools than can a human worker. Examples are a 1200-amp plasma arc cutting torch, a 50-hp hydraulically powered grinder, and a heavy-duty slot blast nozzle. Employing these tools at the increased duty cycle, a single robot system Can, in some cases, produce the same work output as perhaps 1O to 30 human workers. Of course, several more highly skilled technicians will be required to set up and program the semi-autonomous robot systems to perform these tasks.

The following sections outline the main advantages of applying robot systems to shipyard tasks. The description of faster robot programming techniques is presented first because it applies to all the subsequent conceptual designs. Unless a robot can be quickly programmed, productivity increases will be limited. Several conceptual designs are suggested for possible application of robots to shipyard tasks. These concepts will require further study and are described in the implementation plan at the end of this paper.

Faster Programming Techniques

Slow and cumbersome programming techniques have been used to train existing robots to handle batches of identical parts. Programming techniques for NC machine tools, on the other hand, have been developed to the point where a single NC part is often less costly to make than one made by hand.

Most shipyard applications require fabrication of only one, or at most, a few identical parts at a time. To effectively employ industrial robots in these situations, programming time must be reduced drastically.

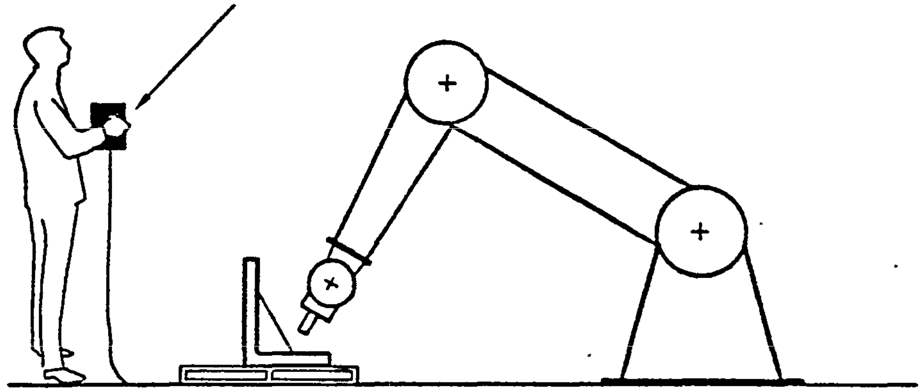
Faster robot programming techniques are described in [1]. These include a control box with proportional joysticks to control the robot, and a separate programming station to manually measure the part and automatically program the robot. Existing shipbuilding data bases may already contain much of the necessary information for CAD/CAM programming. Process modeling, including description of workpieces, robot equipment, and operations, will be required to effectively program robots numerically for single part production.

Robot Welding

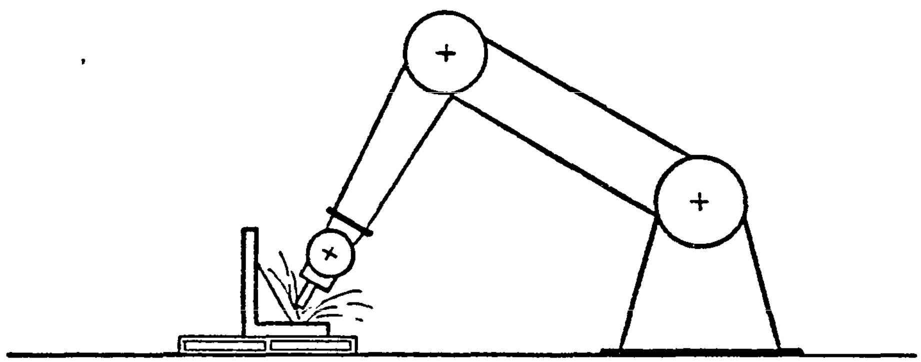
Existing robot equipment is limited in its application to structural welding. Parts to be welded must be cut and jigged to tolerances higher than those economically possible in ship production. Ongoing work is described in [6 to 9]. Precise part fixturing can be eliminated by either manually programming a robot for each individual job or employing NC programming combined with a sensor (e.g., visual sensor) that perceives part fitup variations.

Robot welding can offer substantial cost savings. Anticipated increases in deposition rate (from 2 to 4 lb/hour), operator duty cycle (from 25% to 80%) and productivity factor (from 85% to 98%) may give a system output equivalent to that of 7 men. Robot welding has the added potential for increased uniformity and controllability and decreasing QC costs and rework time.

Using robots for welding could increase productivity by increasing the deposition rate. A robot could move two juxtaposed weld heads along the seam with only slightly increased complexity. Alternately, for some workpieces a two-armed robot system could make two welds simultaneously. Where work is mounted on a positioning table to keep the joint horizontal during welding, a larger puddle can be accommodated and weld current and deposition rate can often be significantly increased (1000 amp). Welding conceptual designs are given in Figures 2, 3, and 4.



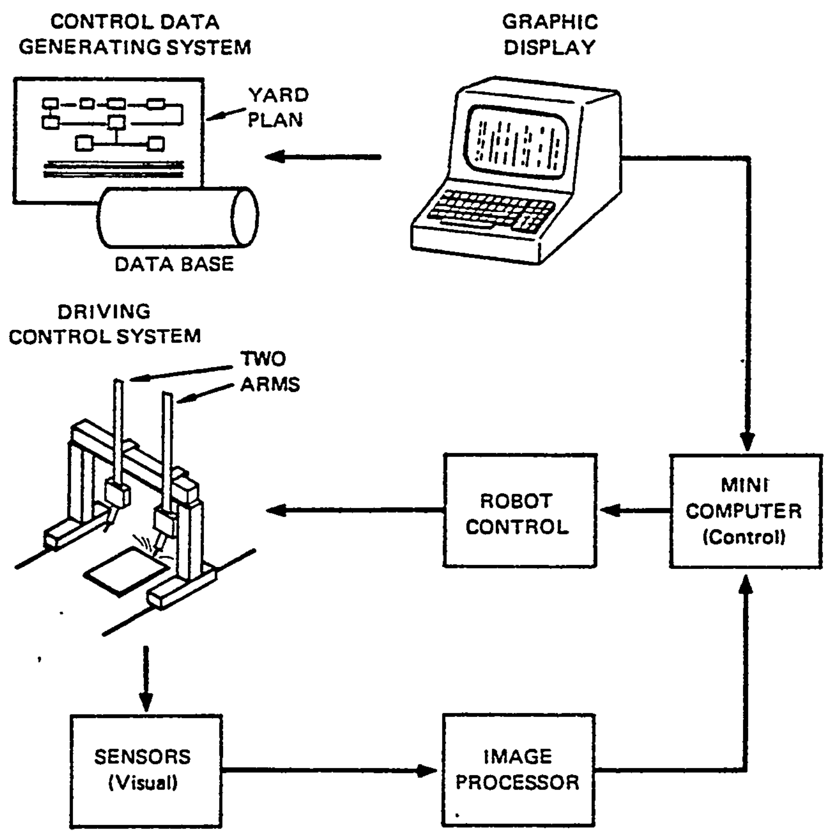
(a) PROGRAMMING A ROBOT FOR PART PROCESSING



(b) ROBOT PERFORMING WORK (SAME STATION)

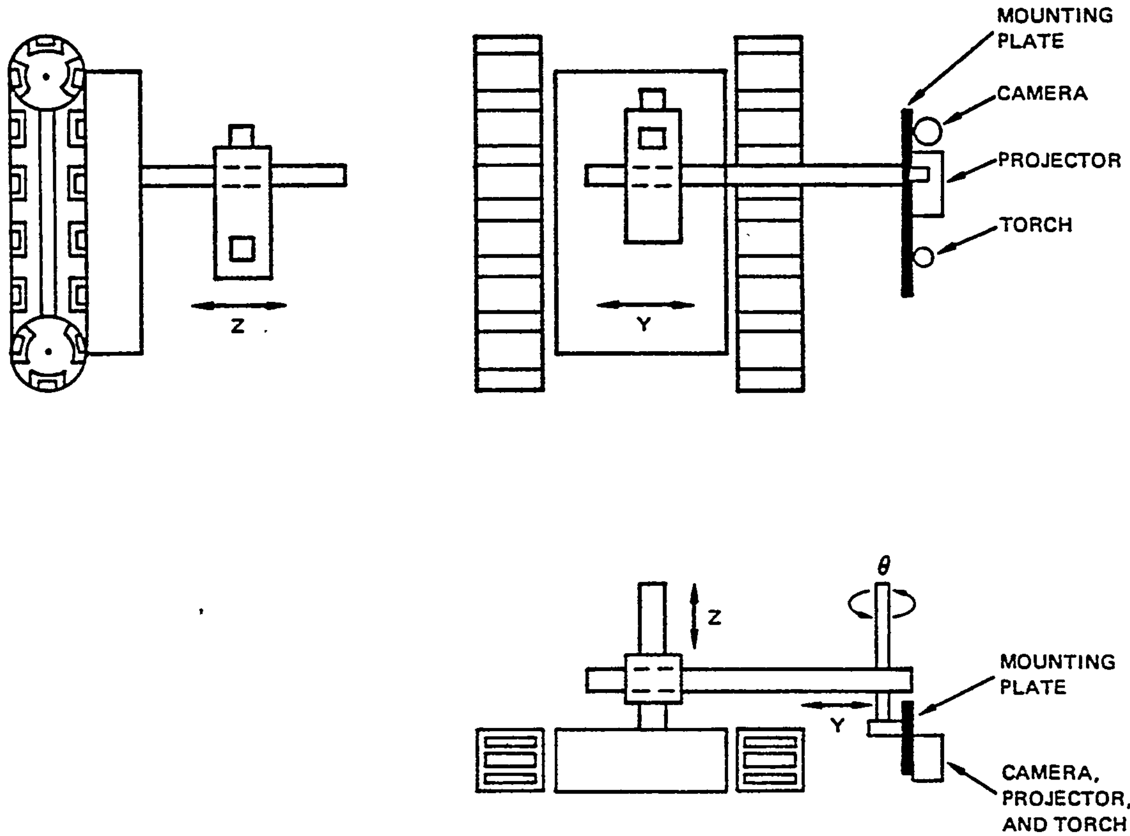
A large, hydraulically powered robot is equipped with a complete welding system (including components such as a torch, wire feed, power, and gas supplies). A workpiece, having been tack welded, is moved to the work station and locked in place. An operator, using specially developed joysticks, positions the weld head at beginning and end points of straight welds to program the system. After programming, the operator turns on the system and assumes a part-time supervisory role during robot welding.

FIGURE 2 FIXED-BASE WELDING ROBOT



An advanced, gantry-mounted, two-arm robot, electrically driven to higher precision than those commercially available, is equipped with dual weld systems. A tack-welded workpiece is moved under the gantry and the robot manually brought to previously defined starting positions on the workpiece. The operator turns control over to a DNC system for controlling the rest of the process. A visual sensor integrated into the weld head enables the unit to locate precisely and follow a variety of joint shapes, including curves. Part-time supervision by the operator is then required.

FIGURE 3 ADVANCED FIXED-BASE WELDING ROBOT



A miniature, tractor-like vehicle is outfitted with a weld system as previously described for the welding robot. An umbilical cable supplies weld and magnetic-track currents, gas, and feed wire to the vehicle. Powerful electromagnets hold the vehicle to the deck, possibly permitting vertical climbing. A visual sensor enables the unit to accurately track various joint shapes once it has been positioned over a seam. As the vehicle moves, a small three-axis manipulator holding the weld head provides the weave pattern and fast corrective movements. The operator positions the unit at the beginning of the seam, turns it on, and supervises.

FIGURE 4 ADVANCED PORTABLE WELDING TRACTOR

Robot Cutting Systems

NC burning tables are now used to flame and plasma cut shapes from flat plates, and computer aids are available to nest parts for maximum stock utilization. NC techniques have also been employed to cut intricately shaped pipe ends and cutouts to fabricate pipe spools.

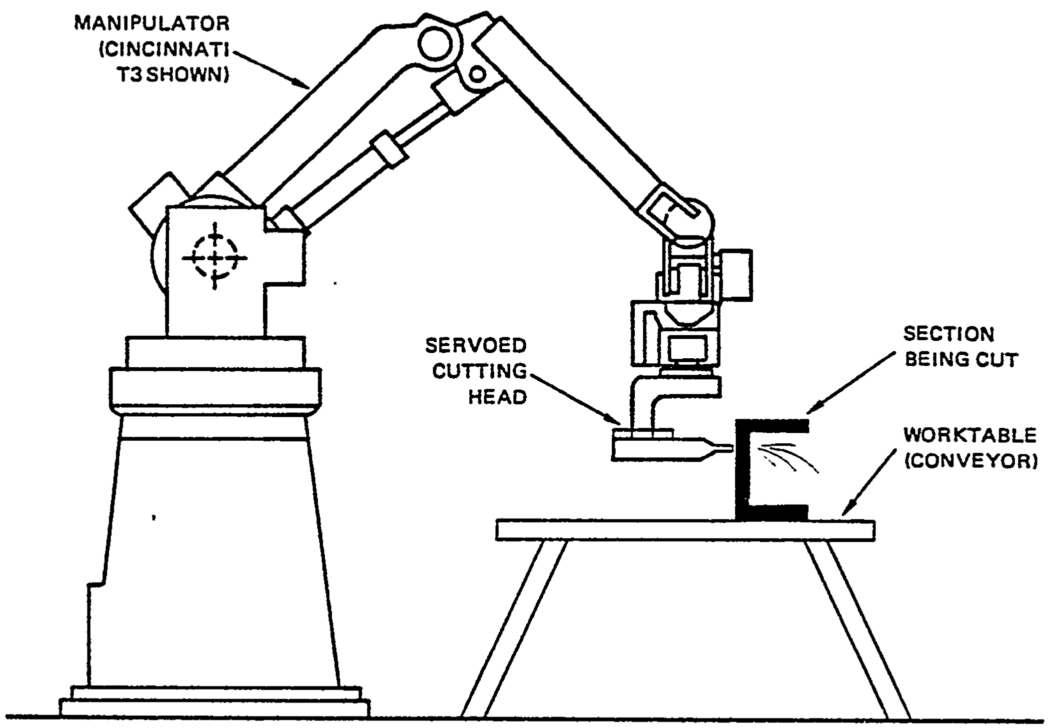
Many irregularly shaped parts cannot be cut with either of these existing NC machines. Of particular interest are long profile sections such as I-beams or T-stiffeners. A frequent problem in cutting these shapes by hand is inaccurate cutting with its resulting repair and rework.

Robot cutting systems offer the potential for substantial cost savings [1]. Mechanized robot cutting offers the advantage of increased speed because high-current plasma arc cutting (PAC) can be employed. PAC could be 10 times faster than oxyfuel flame cutting (OFC). Cutting time (operator factor) is expected to increase from 25% to 80%. These two factors alone could account for a system output equivalent to that of **30** men. Robot cutting also has the potential for uniformity, accuracy, and controlability. Multiple cutting heads further increase productivity. Single and multiple robot cutting concepts are described in Figures **5** and **6.**

Robot Grinding Systems

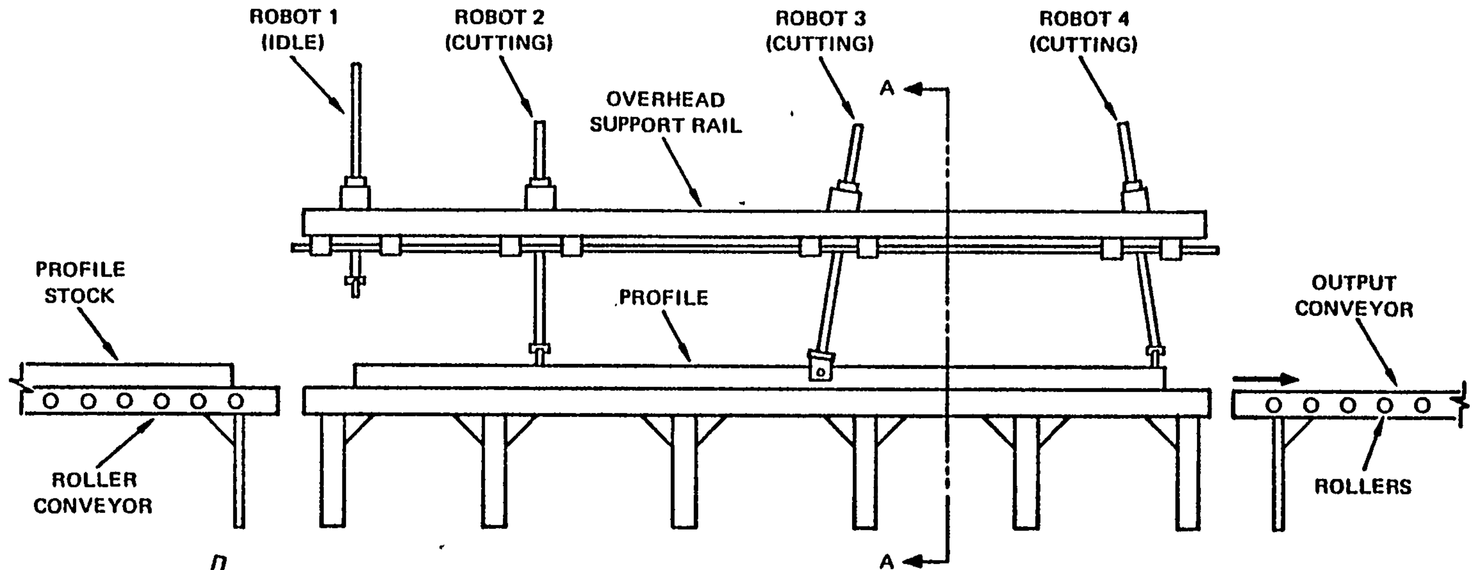
Both heavy grinding, where large amounts of material are to be removed, and touch-up grinding, where slight imperfections are smoothed, were observed in our shipyard visits. Portable grinding tools are limited in power and weight.

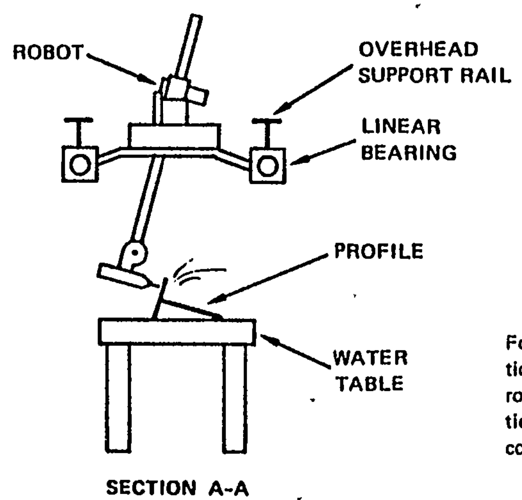
An industrial robot can be outfitted with heavy-duty grinding equipment to perform many of these tasks [10]. In this case the force applied can be increased considerably because robots can continuously handle tools weighing **50** to 100 lbs.



A large, hydraulically powered robot is equipped with a complete burning system, preferably plasma arc cutting (PAC). A workpiece is brought to the station and fixed in place. An operator using joysticks moves the robot to touch cutting lines marked on the part. Once the cutting path has been taught, the operator starts the unit and supervises its operation.

FIGURE 5 FIXED-BASE CUTTING ROBOT





Four computer-controlled electric robots, hung from an overhead carriage, simultaneously cut portions of a long profile section (such as an I-beam) brought under them by a roller conveyor. All four robots are equipped with plasma burn heads. After the profile section has been rolled in and positioned, the operator turns on the unit and the robots begin to cut simultaneously under numerical control.

FIGURE 6 ADVANCED FOUR-ROBOT PROFILE CUTTING STATION

Robot grinding systems offer the potential for large cost savings [1] Robot grinding can be compared to swing-frame grinding: higher grinding pressure and harder abrasive material can be used. Mechanized grinding offers the advantages of higher material removal rates (10 times higher than manual), and grinding time (duty cycle) is expected to increase from 25% to 80%. These two factors can account for a robot system output equivalent to that of 30 men.

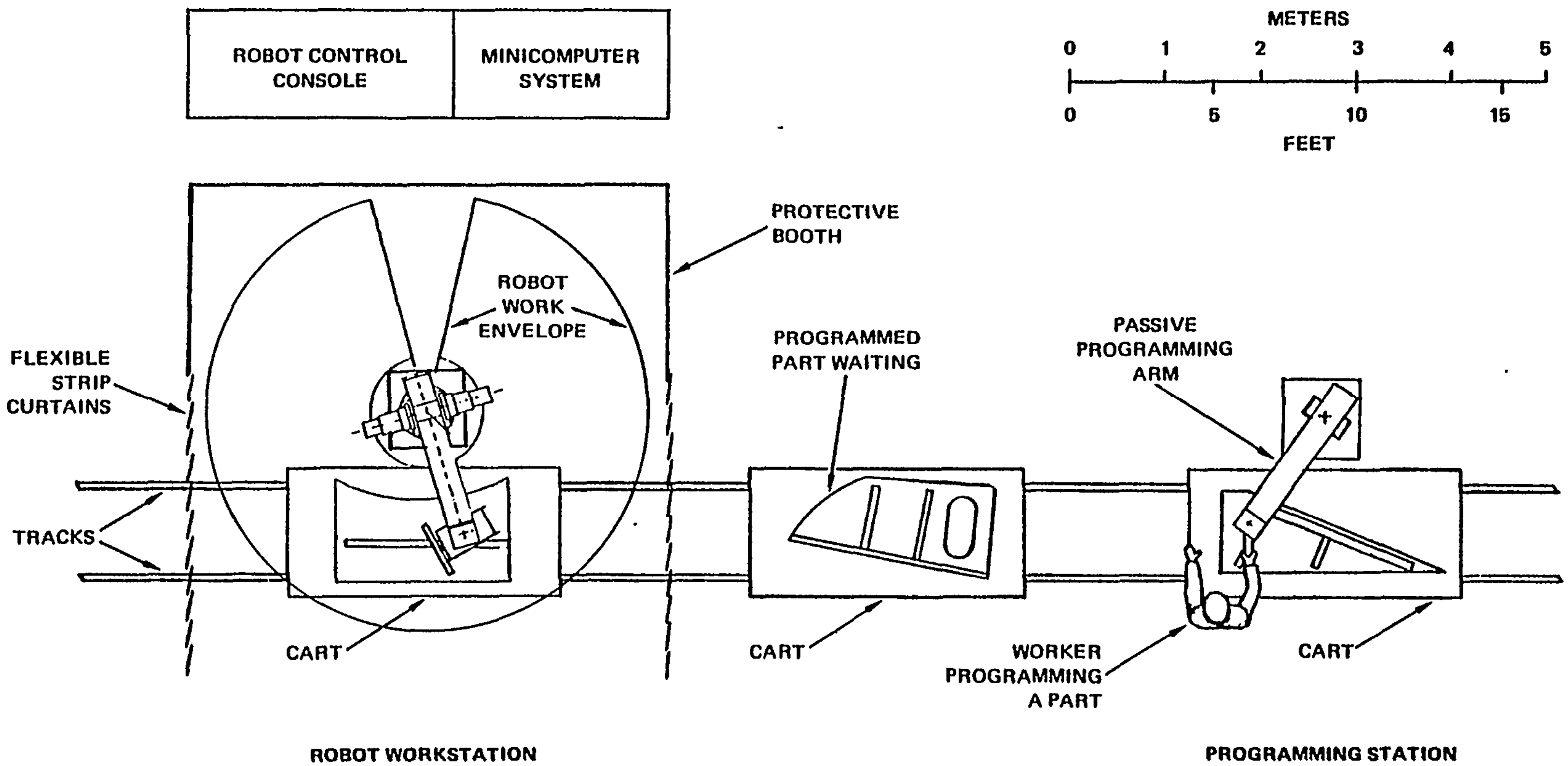
Higher metal removal rates offer an interesting alternative to other forms of metal removal. For example, edges of parts cut from plate or profile, which must frequently be flame-beveled, might be coarse-ground-beveled faster. A robot grinding station concept is presented in Figure 7.

Robot Painting/Blasting Systems

Compared with other robot applications in shipbuilding, these applications would be important for many factors other than economic. Painting and blasting work is dirty, harmful, and undesirable. It is frequently done outdoors with protective clothing and respirators that impede work. OSHA and EPA regulations limit the range of paint and blast substances.

Robot painting offers the potential for improved work conditions and cost savings [I]. Mechanized painting has the potential for increasing paint duty cycle from 25% to 80%. Throughput, however, may be similar to human capability unless multiple heads are used. Painting is fast and programming time will be a limiting factor for state-of-the-art designs. The ability to spray more toxic materials may be an advantage.

Robot blasting offers a higher potential for increased productivity and cost savings than robot painting. Mechanized blasting offers the dual advantages of more powerful blast heads and larger, more effective blast material than can be safely applied manually [ll]. Both of these factors together may increase removal rate by a factor of 10. Blasting duty cycle is also expected to increase from 25% to 80%. These two factors could account for a system output equivalent to 20 to 30 men.



A large, hydraulically powered robot with more than 50 pounds lifting capacity moves a high-power grinding head, Workpieces are moved to the robot station and fixed In place, The operator programs the robot using joysticks to indicate the edges and surfaces to be ground and sets the unit in operation. It automatically follows the trained path at the programmed rate, using feedback from a force sensor.

FIGURE 7 FIXED-BASE GRINDING CENTER

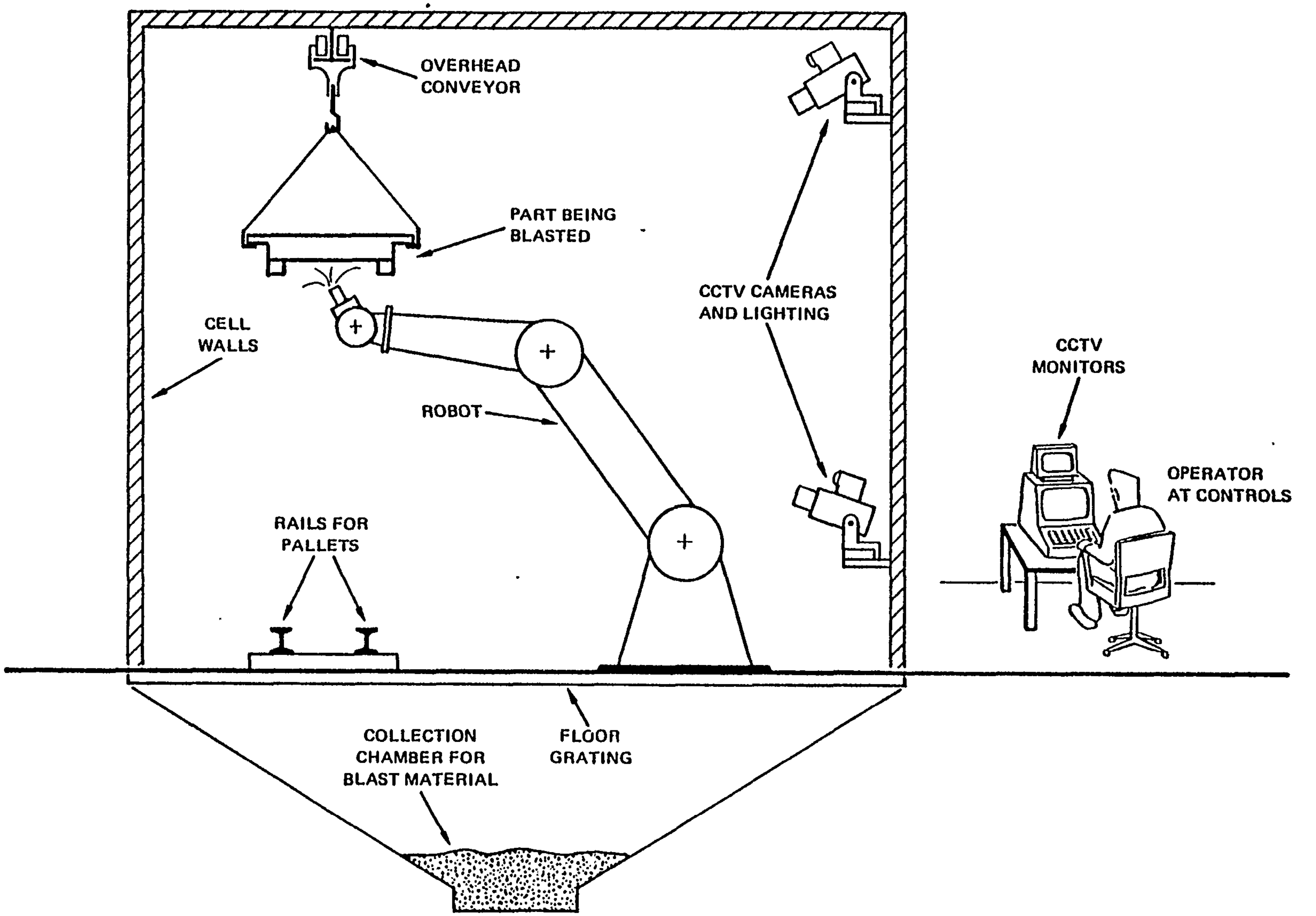
Added advantages of robot blasting are more complete cleaning because of increased velocity and size of shot, applications to other shipyard jobs such as shotblasting welded joints to reduce manual chipping and sanding, and cleaning joints in preparation for welding, ability to install blast cells inside shop areas with ensuing year-round operation, and reduced transportation costs. A robot blasting cell is shown in Figure 8.

Summary of Conceptual Designs

Formulating the required conceptual designs is a complex problem, somehow matching the shipyard needs and the available robot technology. Contending solutions should be flexible, capable of widespread use, highly productive and at the same time low cost, technically robust, and socially acceptable.

Economic factors that bear on the implementation decision are initial developmental and capital expenditures and ongoing operating expenses and benefits (reduction in operating costs and differences in the value of output). Based on simple economic factors, a standardized cost schedule was established for determining the ROI of the conceptual designs [1]. Table 2 summarizes these results. The initial cost includes estimates of robot, support equipment, and installation. Production costs include estimates of system output and charges in the value of the output measured in man-years/year.

Cost analyses indicate that cutting, blasting, and welding tasks are principal candidates for present robot technology. The large increases in productivity possible with plasma arc cutting (PAC) robots give cutting a more favorable initial economic rating than welding. However, six times as many manhours are devoted to welding as to cutting [2], and this unbalance suggests that welding concepts, once implemented, will be put to far wider use than cutting concepts. Attention must be paid, however, to system throughput: robot system capacity (as high as 10-30 men) should not exceed the work available.



A robot arm equipped with a heavy-duty blasting head is mounted inside an enclosed cell having open-floor grating and a recycling system for the blast materIal. A part is brought into the cell on either an overhead conveyor or railroad-type tracks on the floor and positioned in front of the robot, An operator In an adjoining room operates the arm with joystick controls and closed-circuit TV monitors to blast the part.

FIGURE 8 FIXED-BASE REMOTELY CONTROLLED BLASTING CELL

Table 2

COST/BENEFIT SUMMARY OF CONCEPTUAL DESIGNS

Concept	Initial* Cost($)	Equivalent Production Cost (man yr/hr)	Estimated** ROI(%)
Fixed Welding Robot	**123,000**	**3.22**	**34**
Advanced Fixed Welding Robot	**200,000**	**5.85**	**38**
Advanced Portable Welding Tractor	**79,000**	**.67**	**5**
Fixed-Base Cutting Robot	**126,000**	**17.4**	**206**
Advanced Fixed 4-Robot Cutter	**264,000**	**45**	**251**
Fixed Grinding Robot	**130,000**	**15**	**190**
Fixed Remote Blast Cell	**223,000**	**10.5**	**78**

* Initial costs include estimates of robot, support equipment, and installation (rough) cost only. They do not include robot software, factory reorganization, redeployment of workers, or other costs of change.

** ROI figures based on a simplified analysis for comparison purposes [1]. Unknown requirements for additional support operations personnel at higher skill levels will reduce ROI in this table.

Actually, we believe that all the identified concepts are candidates for robot automation. Shipyard management and the Navy must make the final selection based on their own requirements.

SUGGESTED IMPLEMENTATION PLAN

Implementation of any robot concept will require additional study and more refined plans and cost estimates. In any case, more refined conceptual designs will be required before investment in such programs will be warranted by the shipbuilding industry.

Proof of concept work is probably the next step in the implementation of these new conceptual designs. Such a demonstration could be given by a robot manufacturer or by a shipyard with advanced development capability and desire to increase productivity in a particular area. A joint venture between a robot manufacturer and a shipyard might be more successful: the PUMA robot system resulted from a cooperative arrangement between Unimation, Inc. and General Motors. A development contract from the federal government could expedite this process.

General guidelines as to how to define a robot system and demonstrate the concept are given in Table **3.** The items may be applied to the conceptual designs in this paper; additional details for a particular design are presented in the main report [1].

Table **3.**

OUTLINE OF SUGGESTED ROBOT IMPLEMENTATION PLAN

1. <u>Task Specifications</u>

   1.1 Specify tasks by the quantity of each type to be performed by location in a typical shipyard. Labor input is only a rough indicator--footage or parts count may be preferable.

   1.2 Look for other tasks not performed by a robot system that could be more economically done by it, and also tasks that could be funneled through the system to increase productivity.

   1.3 Summarize the quantity of work to be done at suggested installation work sites (number of workpieces, work per piece, transportation means, alternate installation plans, etc.).

2. Detailed Conceptual Design

2.1 Survey the types of robot and support equipment available to implement the conceptual design. Obtain vendor quotes.

2.2 Survey the equipment available for mounting on the end of the robot (workhead) that is applicable to the task considered. Often robot workheads can be made by modifying present shop equipment or semi-automatic workheads.

2.3 Survey types of sensors that are commercially available to monitor proper system operation or to provide the required feedback and control information.

2.4 Develop detailed system concept including robot, workhead, sensors, computer system, software modules, and range of tasks.

3. In-Plant Technology Demonstration

3.1 Develop and build a workhead package suitable for the selected robot, process, and sensor.

3.2 Develop and build a workstation demonstration facility including robot, control, programming, and operation system.

3.3 Demonstrate operation of the workhead package on the workpiece family chosen.

4. Effectiveness Study

4.1 Run timed experiments on candidate workpieces.

4.2 Document performance measurements such as setup time, programming time, speed of operation possible (as ft/min, pounds/hour, etc.), accuracy obtained, quality obtained, problems encountered, throughput (man-hours), operator time (man-hours), system cost, and expected ROI.

4.3 Estimate time and cost of training supervisory and maintenance personnel or retraining existing personnel.

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